Process-oriented diagnostics in the polar regions. Part 1: Quantifying model complexity for the simulation of Arctic sea ice.

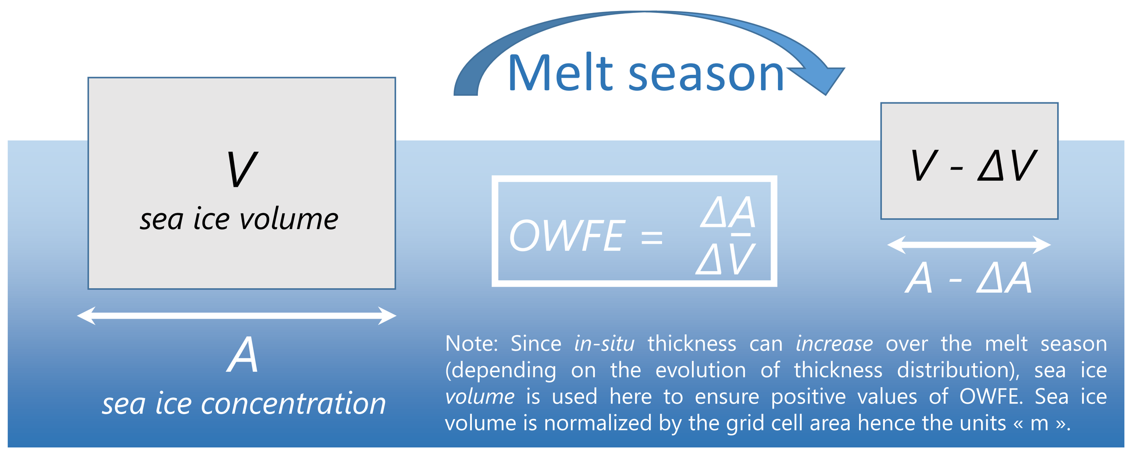
François Massonnet[1,2], Martin Vancoppenolle, Detelina Ivanova, Olivier Lecomte, Paul Hezel, Thierry Fichefet
[1] ELIC/TECLIM, Université catholique de Louvain, Belgium and [2] Barcelona Supercomputing Center Earth Sciences Department, Spain, contact: francois.massonnet@bsc.es

Motivation

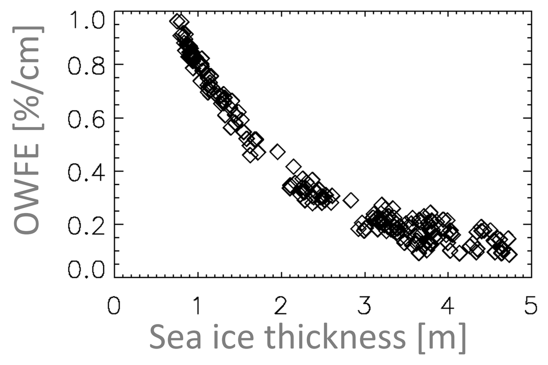
A main challenge for the upcoming CMIP6 is to design metrics that reflect the ability of climate models to **simulate processes rather than numbers**. We take a first shot at it by proposing three Arctic sea ice diagnostics that quantify how a variety of models (with different levels of complexity) simulate **essential processes** such as the ice-albedo feedback, the ice growth-thickness feedback and the sea ice thickness-drift relationship. **Note that a companion poster describes similar metrics for *Antarctic* ocean and sea ice simulations (Lecomte and colleagues).**

Example 1 – Ice Melt: The Open Water Formation Efficiency

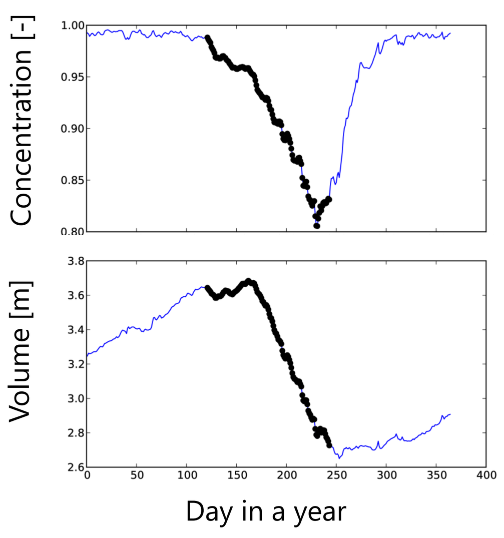
Mechanism investigated: the ice-albedo feedback

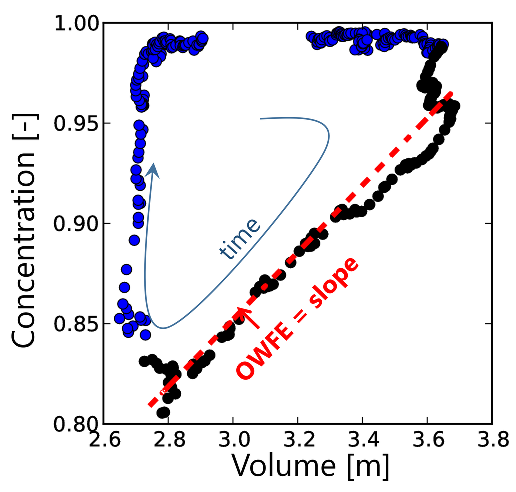


It is easier to produce open water when ice is already thin (from Holland et al., GRL, 2006)

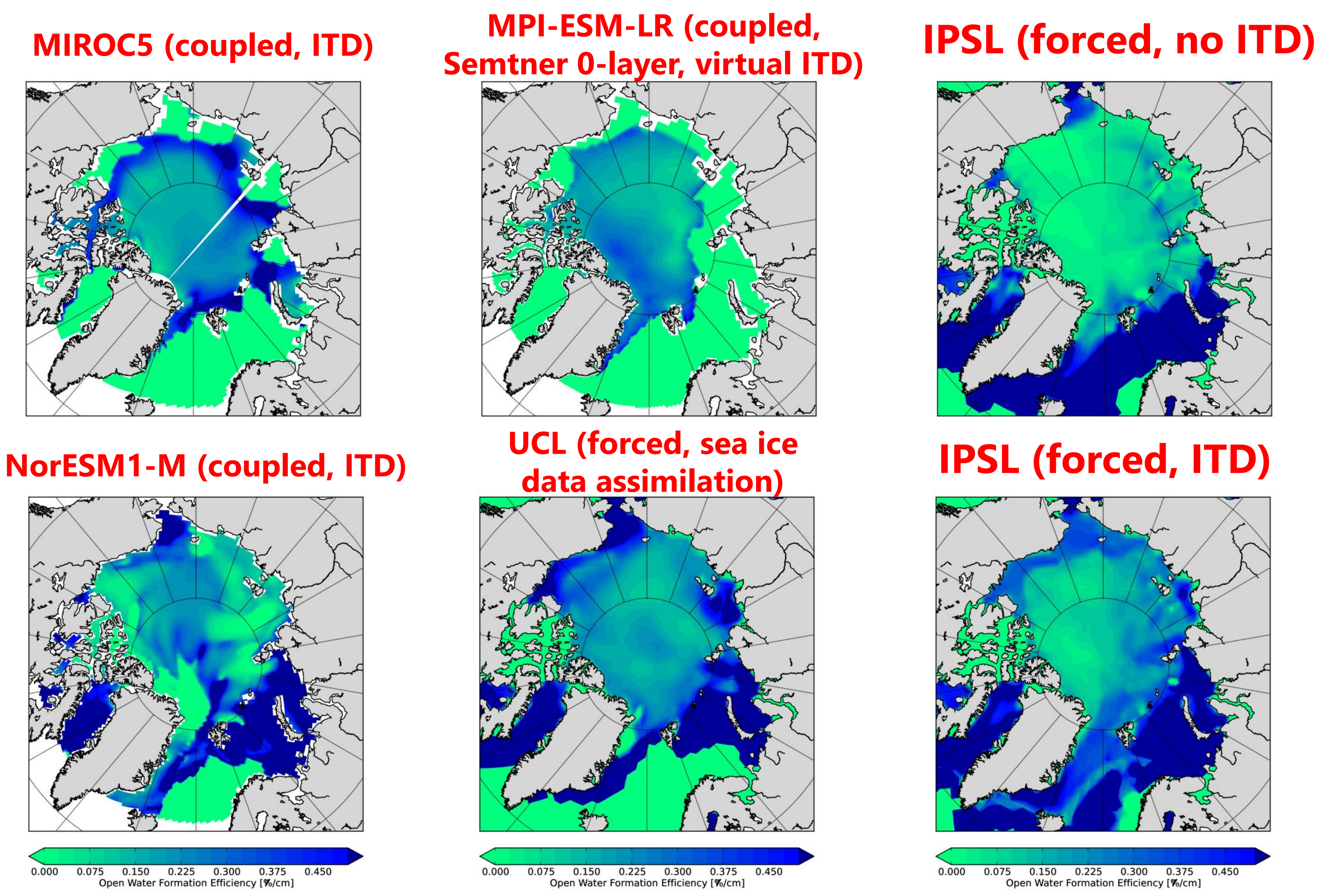


The Open Water Formation Efficiency (OWFE) was first introduced by Holland et al. (GRL, 2006) to understand the origins of simulated abrupt sea ice reductions over the 21st century. **It quantifies the ability of a model to produce open water during the melt season** and is therefore a proxy for the ice albedo feedback. **Moreover, it depends inversely on the baseline sea ice thickness**: thin ice melts away more easily.





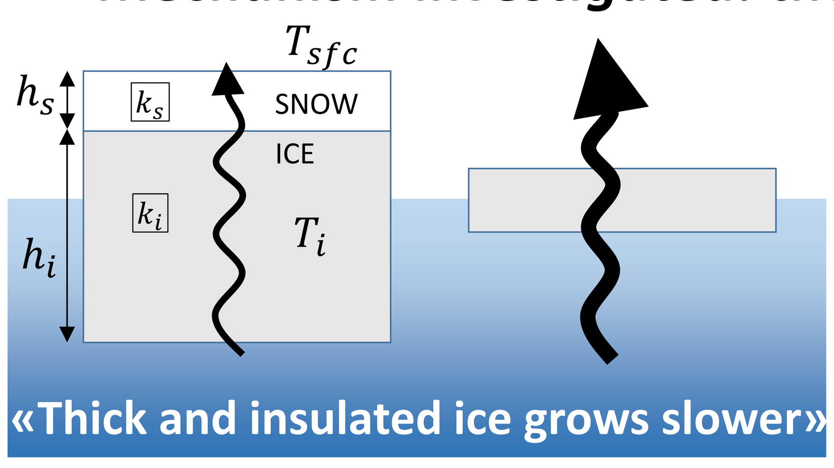
The OWFE is estimated for each year at every grid point, as the regression between sea ice concentration and volume over the melt season. Note that these changes account for both thermodynamic (melt) and dynamic (including advection, ridging and rafting) processes.



A remarkable property of OWFE is that is is **stable** with respect to the forcing (not shown on this poster). It is an a posteriori confirmation that this diagnostic quantifies well a process, which is supposed to be the same regardless of the year considered. The OWFE diagnostic also highlights that simulations with a more complex sea ice model are better able to reproduce the inverse relationship noted above. Note: ITD="ice thickness distribution".

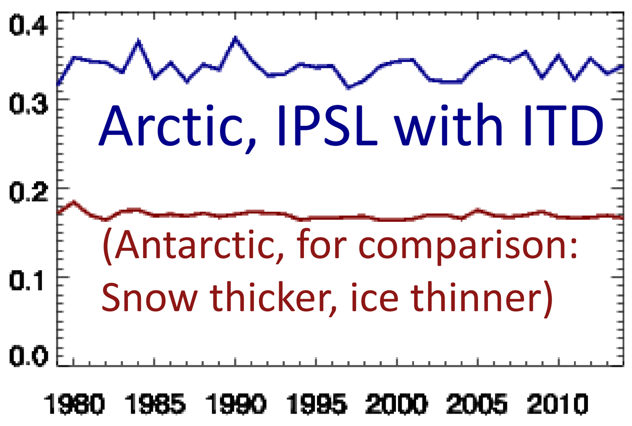
Example 2 – Ice Growth: the Heat Conduction Index

Mechanism investigated: the ice-growth-thickness feedback

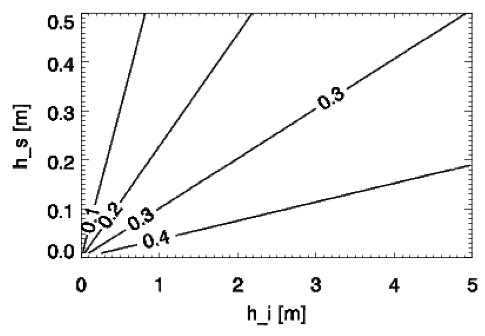


$$HCI = \frac{\partial T_i}{\partial T_{sfc}} = \frac{1}{2}\left(\frac{k_s h_i}{k_i h_s + k_s h_i}\right)$$

The index can be diagnosed from respective thicknesses and conductivities of snow and ice, **as long as conductivities can be assumed constant** (they depend in reality on local conditions, salinity)

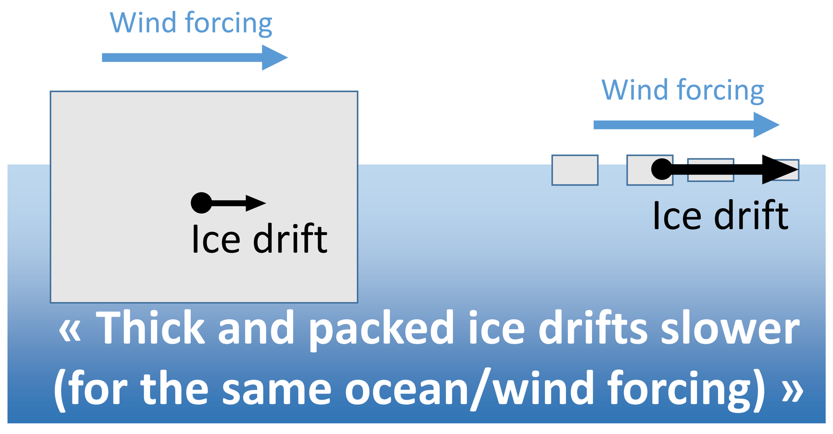


Like the OWFE, the HCI diagnostic is very stable w.r.t. interannual variations of the forcing. This is because it is preserved under proportional increases of snow and ice thickness



Example 3 – Ice Dynamics

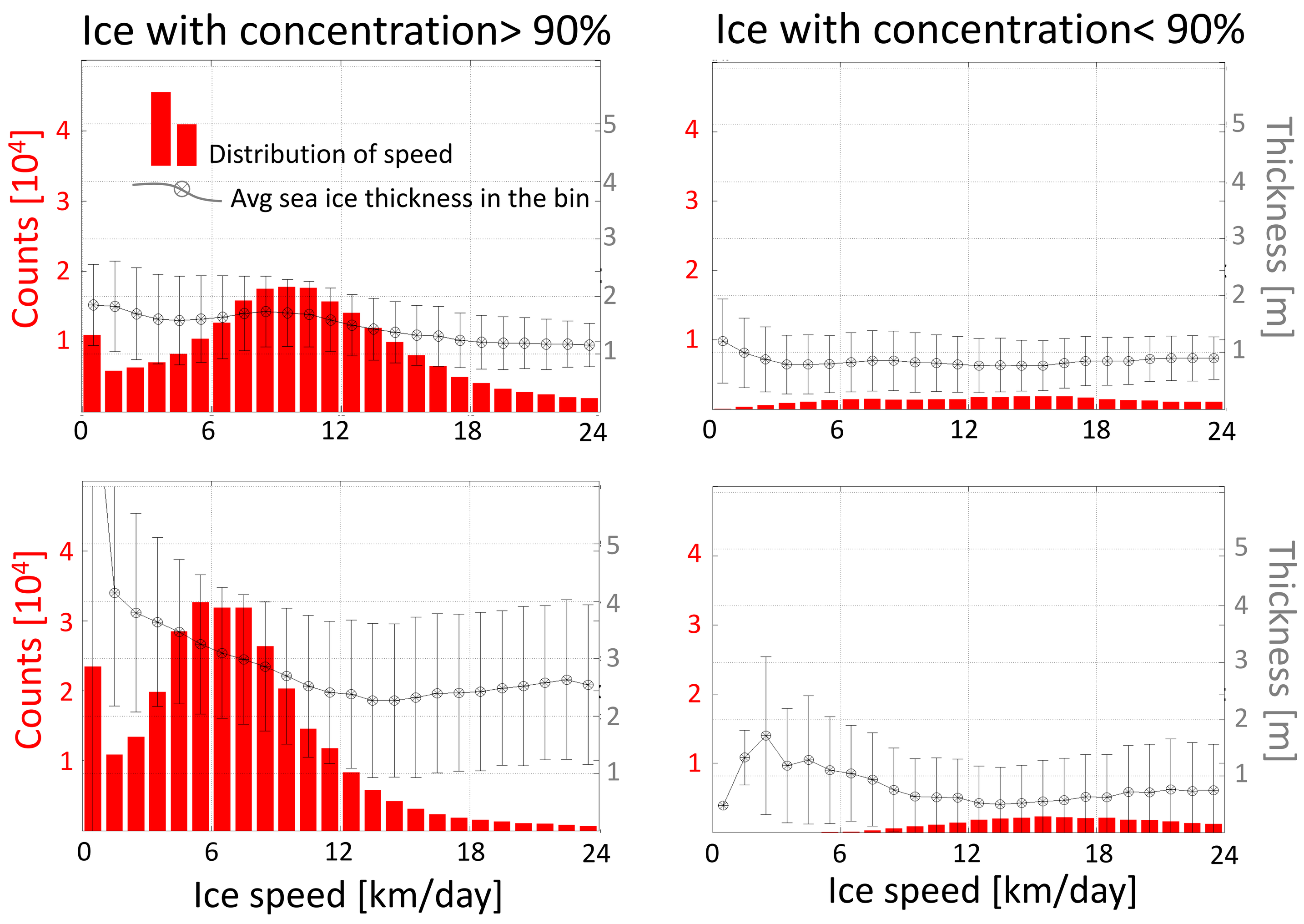
Mechanism investigated: the sea ice thickness-drift relationship



Sea ice is a complex body, for which better rheologies are currently being tested. One basic relationship that a model should simulate is the « thickness-drift » relationship: Packed (typically >90% concentration) and thick ice drifts slower, all other things being equal.

MPI-ESM-LR
- VP rheology
- Virtual ITD
- 0-layer thermodynamics

NorESM1-M
- EVP rheology
- Full ITD & mechanical redistribution
- Bitz and Lipscomb (JGR, 1999) thermodynamics



MPI-ESM-LR (CMIP5 model with simple sea ice component) shows hardly any dependence of sea ice speed on sea ice thickness for the two regimes of drift.

Conclusions, lessons learned and recommendations:

- It remains to be seen **how these process-based metrics relate to larger-scale, climate metrics** (e.g., extent, volume, their respective trends) and how well they explain spread between projections.
- Process-based diagnostics do not imply to derive single numbers to quantify performance. An analysis of appropriate figures is equally justifiable. **Expert judgement also has a strong role in that respect**.
- Given the stability of the proposed diagnostics, **targeted measurements over one year (e.g., the Year of Polar Prediction) could be enough** to apply **emergent constraints to the simulations**.
- One critical aspect over the coming months will be to insert these diagnostics directly in the model codes ("on-line" metrics) and/or to **rethink the list of variables to be saved**.

Workshop on CMIP5 Model Analysis and Scientific Plans for CMIP6, Dubrovnik, Croatia, 20-23 October 2015